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A Meteosat Bayesian Cloud Fractional Cover Climate Data Record:

evaluation, homogeneity assessment and intercomparison with existing climate data records

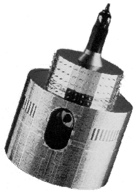
Jędrzej S. Bojanowski[1,2], Reto Stöckli[2], Anke Duguay-Tetzlaff[2], Stephan Finkensieper[3]

[1]Remote Sensing Centre, Institute of Geodesy and Cartography, Warsaw, Poland
[2]Federal Office of Meteorology and Climatology MeteoSwiss, Zurich, Switzerland
[3]German Weather Service DWD, Offenbach, Germany

What is a cloud and why to study clouds?

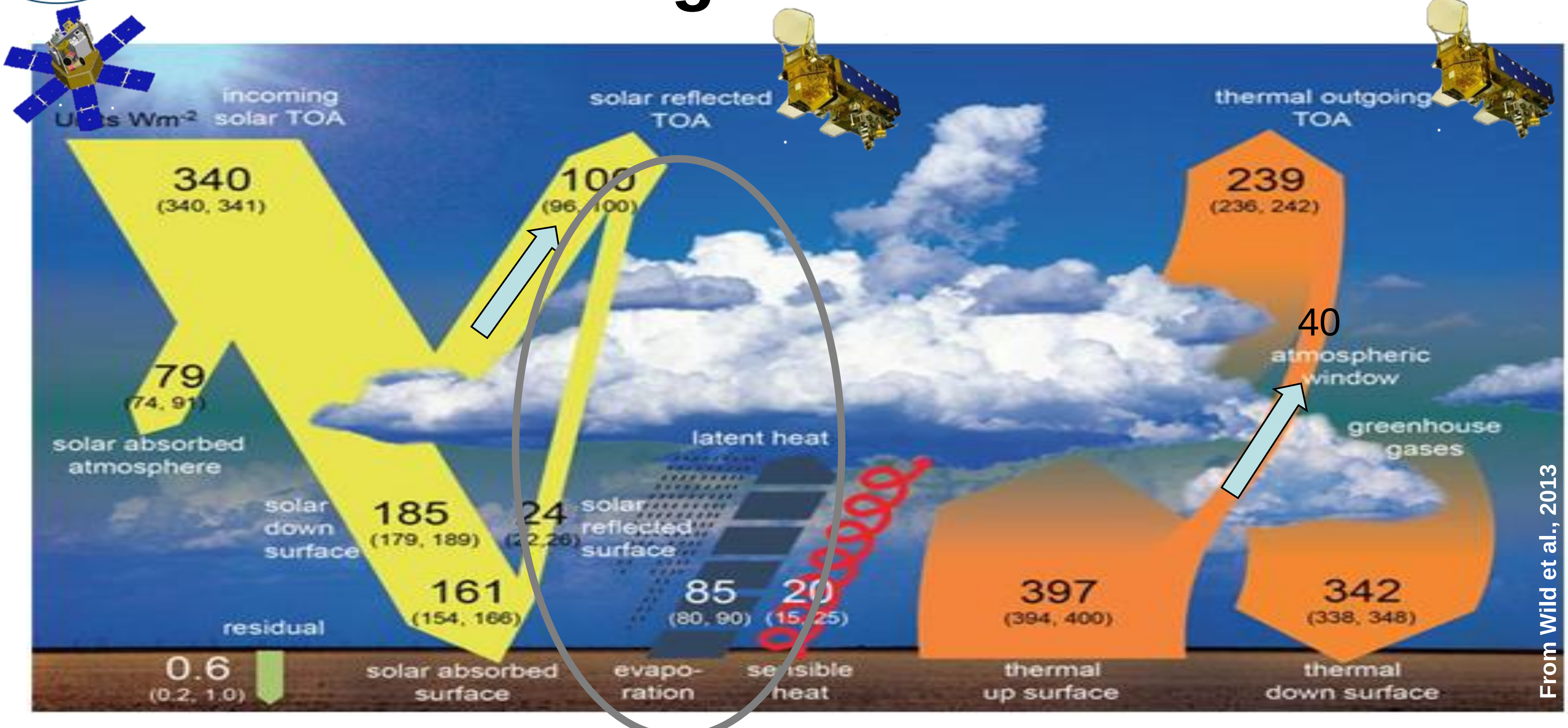
What is a cloud?

- A collection of liquid or frozen particles floating in the atmosphere and sustained by vertical motion (updrafts)



- We identify clouds by their ability to reflect sunlight and by the temperature of their cloud tops, i.e., their brightness in visible and thermal imagery

Radiation budget



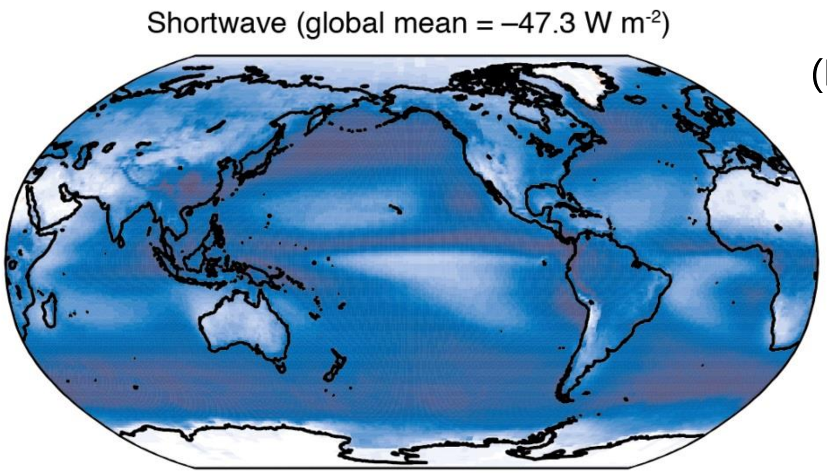
- 22% (76 Wm^{-2}) of incoming solar radiation is reflected by clouds and atmosphere – this is 76% of the total radiation reflected back to space
- Clouds double Earth's albedo from 0.15 (no clouds) to 0.31 (including clouds)

Cooling effect

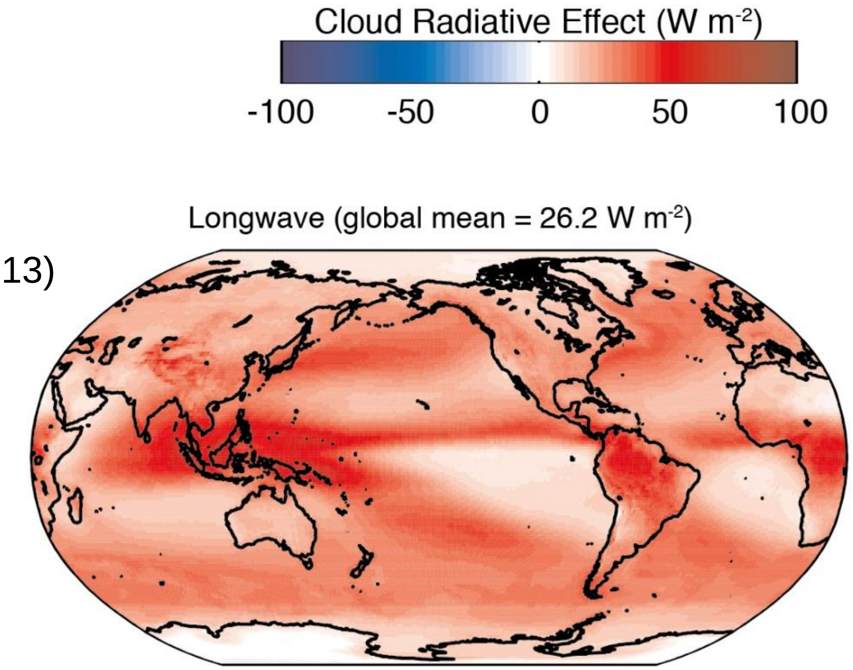
- Only 10% (40 Wm^{-2}) of infrared radiation emitted from Earth's surface is not trapped by the greenhouse gases
- 65-85% of the trapped radiation is intercept by water vapour and cloud droplets

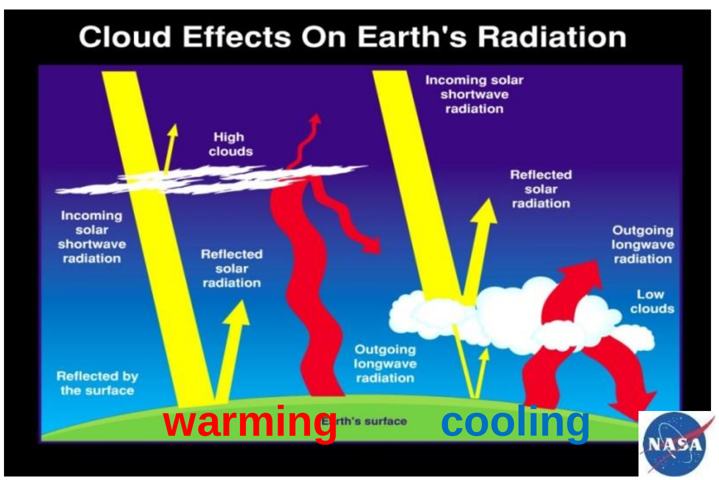
Warming effect

Cloud forcing



(IPCC, 2013)





- ➢ The most uncertain component of climate models is cloud feedback
- ➢ For all cloud types, it has been estimated at 0.6 Wm^{-2} for 1°C of air temperature increase, but with weighty uncertainty ranging from **-0.2 to 2.0** Wm^{-2} (IPCC, 2013)

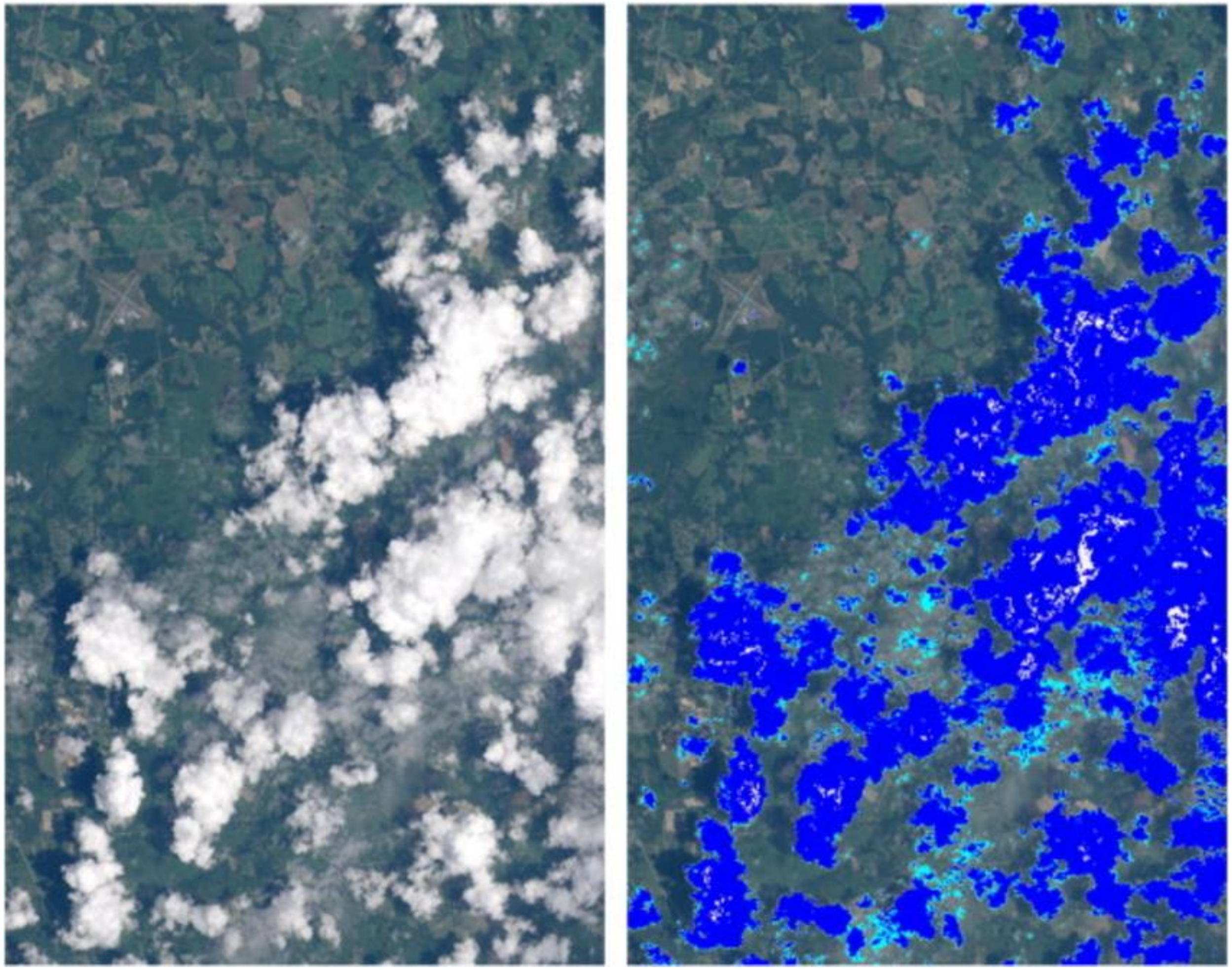
Rationale

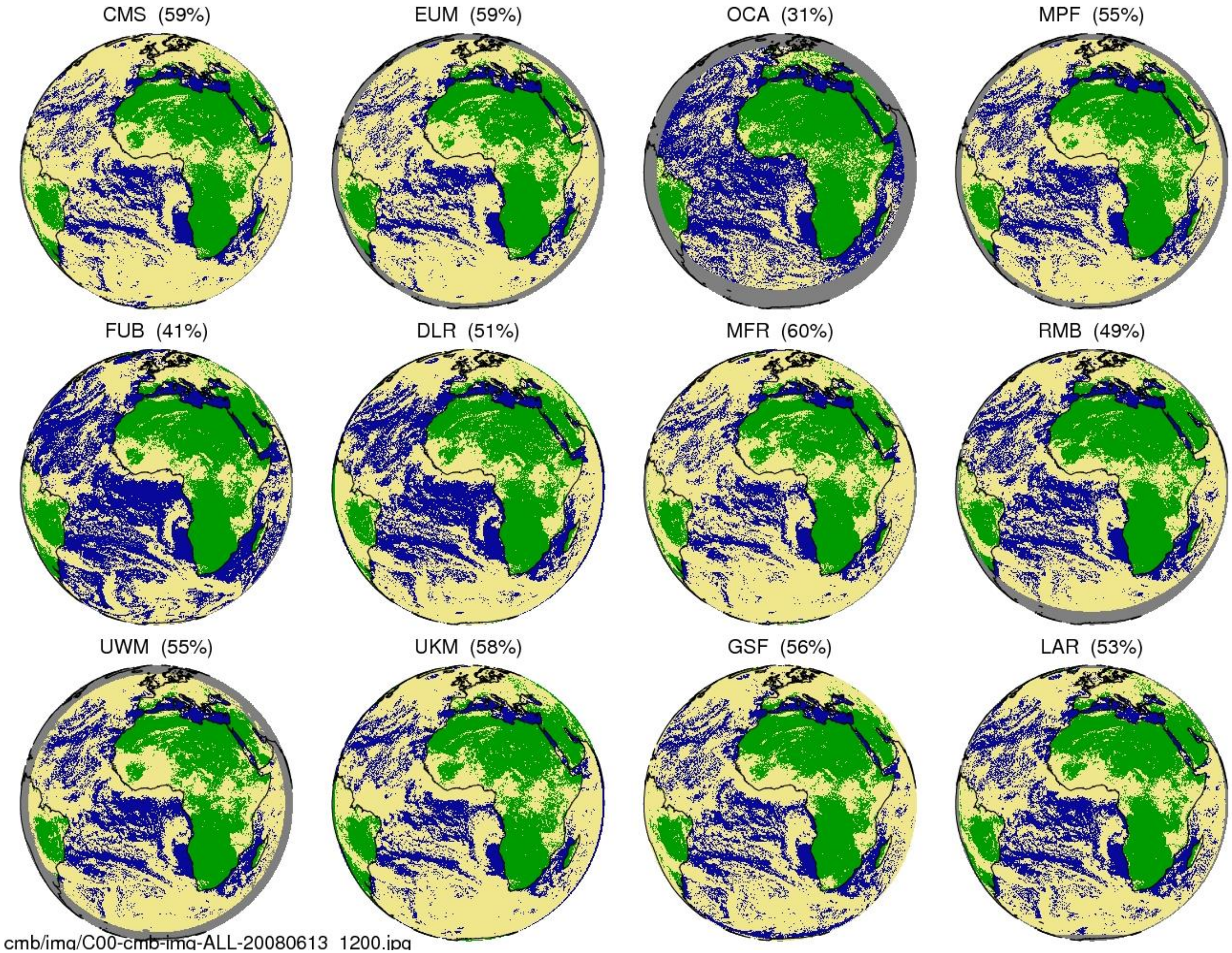
*„The net radiative feedback due to all cloud types combined is **likely** positive. Uncertainty in the **sign** and **magnitude** of the cloud feedback is due primarily to continuing uncertainty in the impact of warming on low clouds."*

Cloud properties are within a list of **essential climate variables (ECVs)** (with a special emphasis on satellite-based retrievals) of the Global Climate Observing System (GCOS), a part of the United Nations Framework Convention on Climate Change (UNFCCC)

The ultimate projects' objective has been to deliver cloud climate data records that can contribute to the better understanding of cloud-climate interactions and cloud feedbacks, and in turn to reduction of uncertainty in future climate projections.

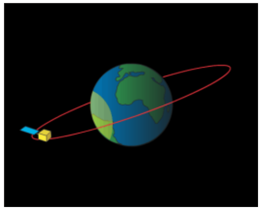
Cloud masking



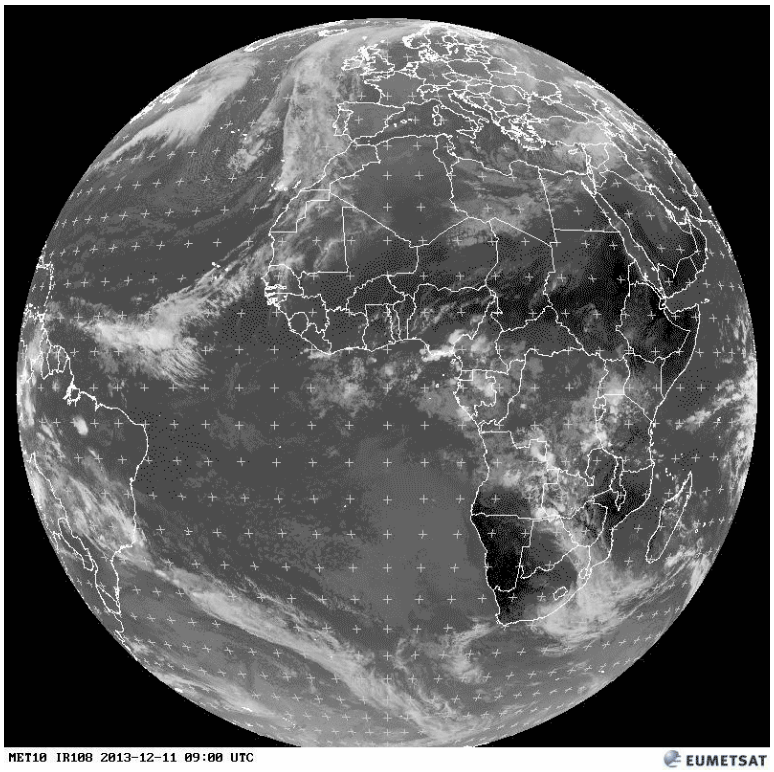

CMS (59%)
EUM (59%)
OCA (31%)
MPF (55%)
FUB (41%)
DLR (51%)
MFR (60%)
RMB (49%)
UWM (55%)
UKM (58%)
GSF (56%)
LAR (53%)
cmb/img/C00-cmb-img-ALL-20080613_1200.jpg

Meteosat Climate Data Record

Meteosat data



Geostationary

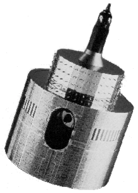


- Fixed position ~36,000 km above equator
- Hemisphere scanned every 15 or 30 minutes
- Diurnal cycle resolved, no orbital drift issue
- Limited spatial coverage

Different spectral resolution:

- First Generation / MVIRI (2/3 channels), 1982-2005:
  - 0.5-0.9 µm
  - 11.5 µm
- Second Generation / SEVIRI (3/12 channels), 2005-2015:
  - 0.6 µm + 0.8 µm → broadband
  - 10.8 µm

Sensor calibration



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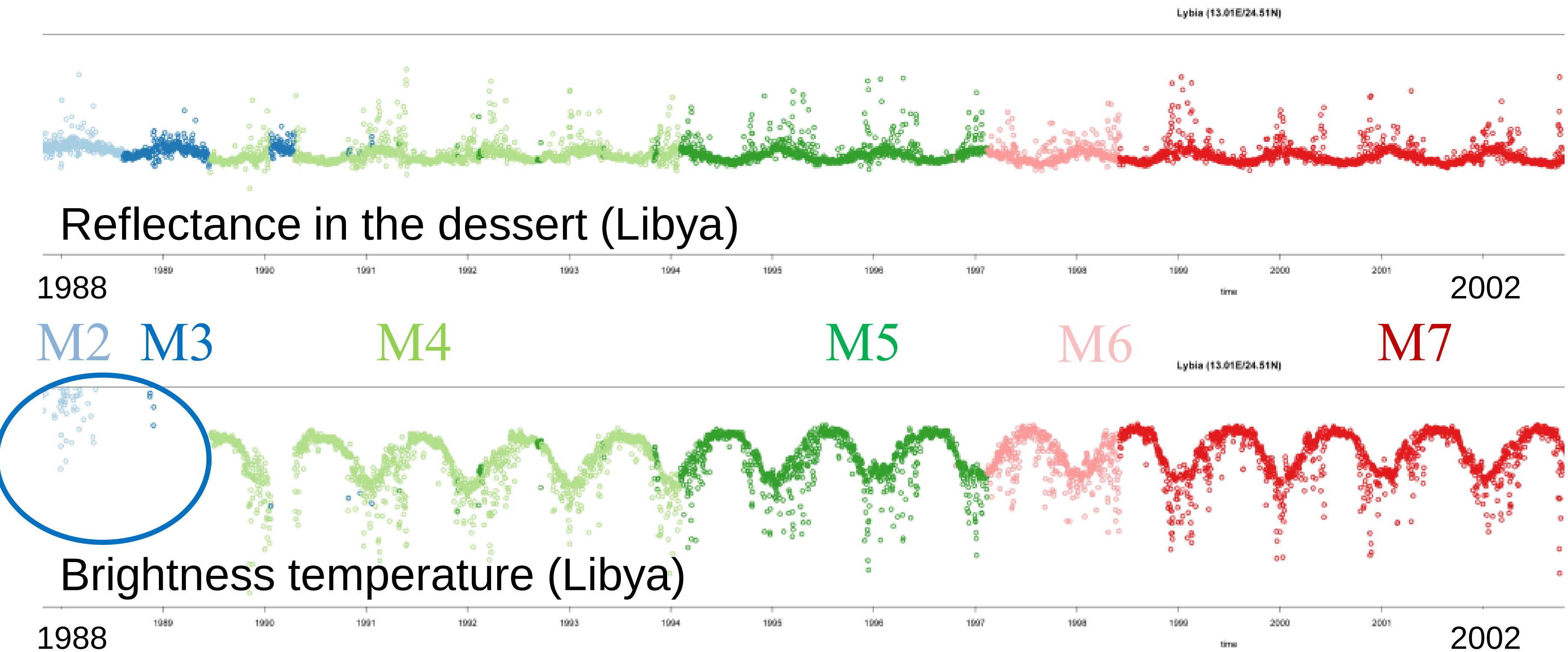
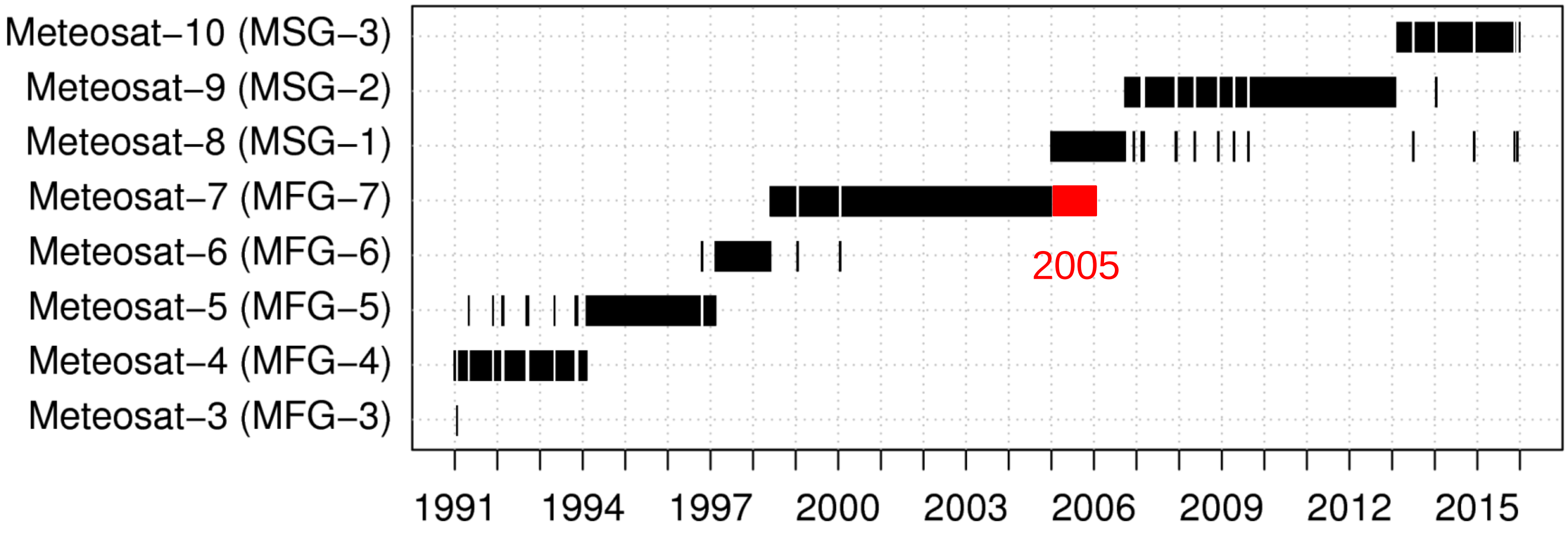
Yves Govaerts & Viju John (EUMETSAT)



- Visible channel stable
- Thermal channel calibrated after 1991

Meteosat data



(Bojanowski et al., 2017)

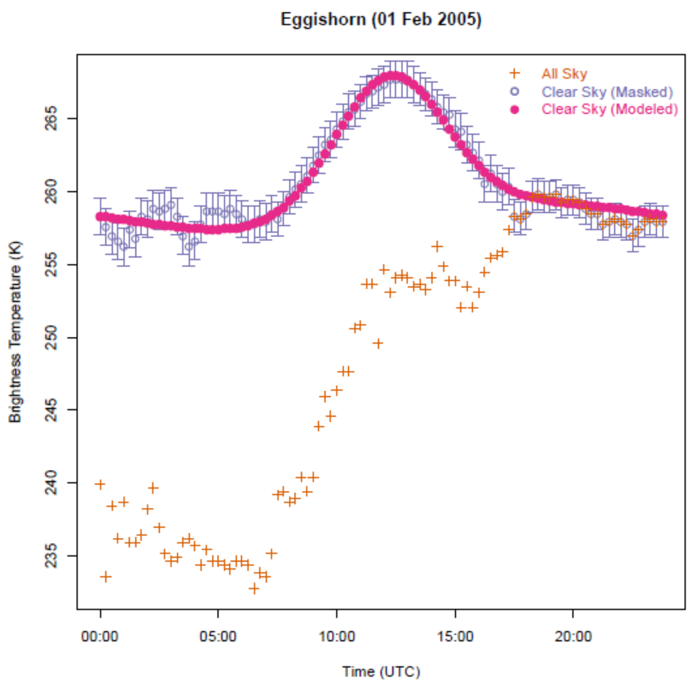
Tests

Cloud masking → background fields

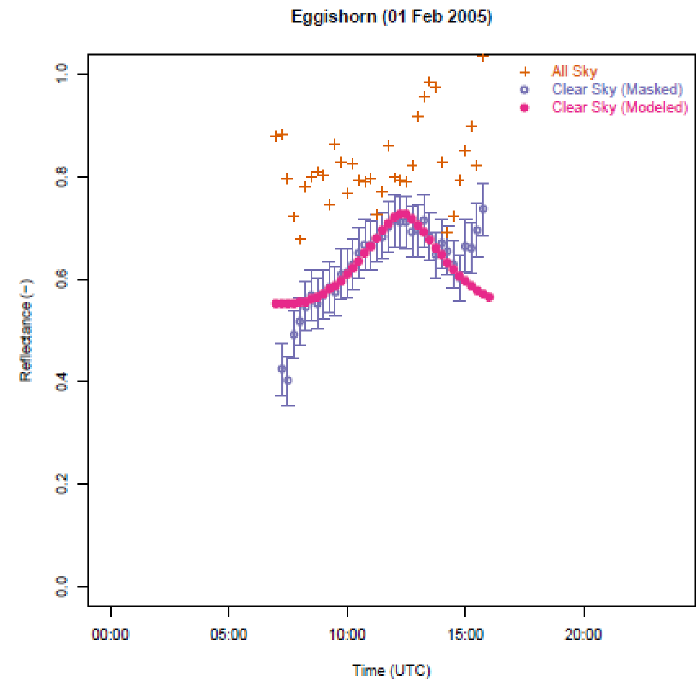
Test name	Test basics
Temperature score	$T_{10.8}$ vs $T_{cloud\text{-}free}$
Brightness score	ρ_{VIS} vs $\rho_{cloud\text{-}free}$
Spatio-temporal Temprature Variance Score	STT – for cloud boundaries and low level clouds with weak *T* signature: low – for temporarly static, but spatially varying high – for temporarly and spatially varying
Spatio-temporal Reflactance Variance Score	STR – same for brightness
Temporal Temperature Variance Score	TV – for broken clouds: variability within ±1 hour
Day-night separation	f_{night} – smooth day/night transition = 1 for θ_s<85° = 0 for θ_s>88°
Day-night regression	Compensation for less tests during daytime

Modeling (self-constrained and self-contained) background fields

Clear-sky Brightess Temprerature



Clear-sky Reflectance



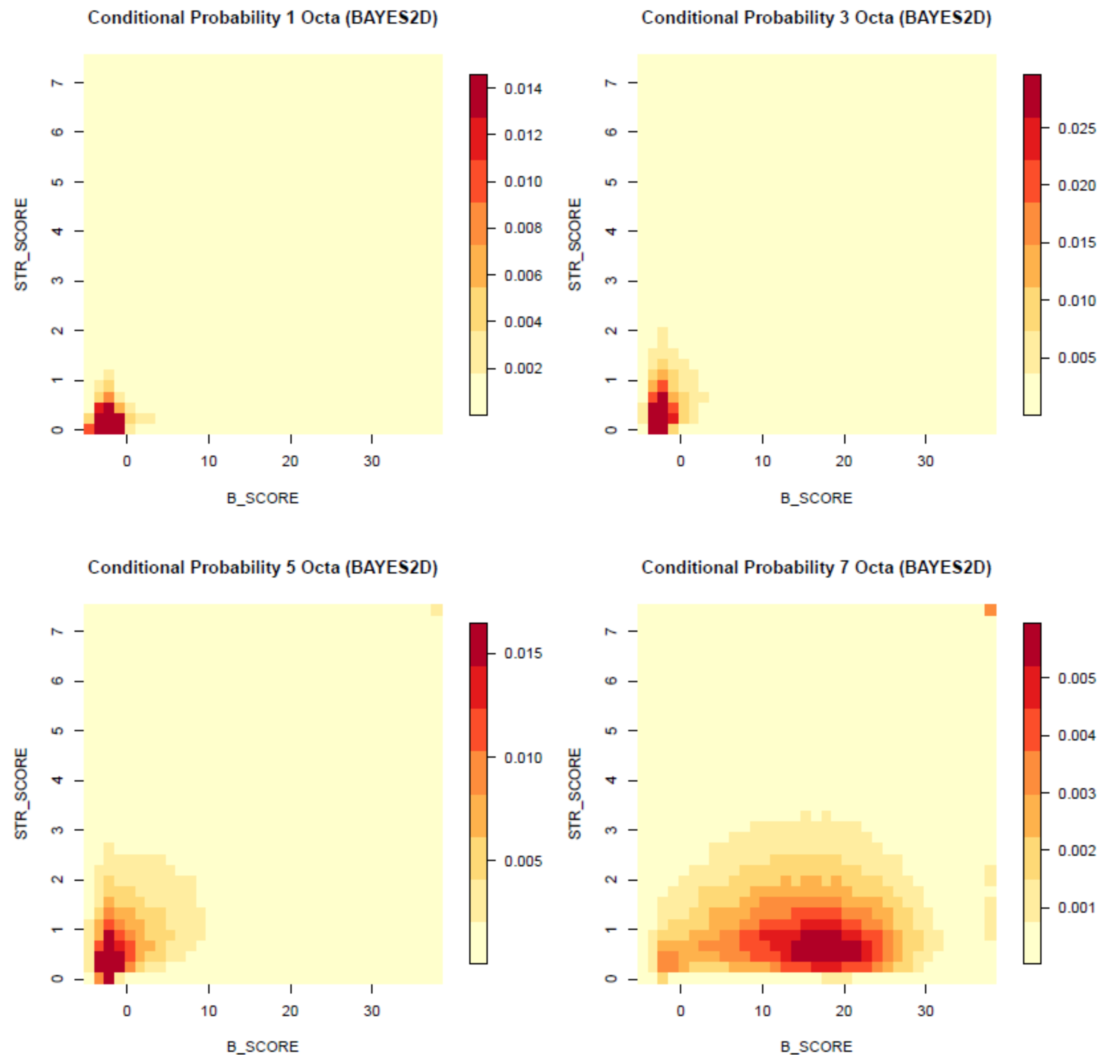
Mannstein et al. (1999)
Göttsche and Olesen (2009)

ERA-Interim skin temperature used as a first guess

The model is built on the Modified Lambert-Beer equations (Müller et al., 2004) for atmospheric scattering, the back-scattering properties of land surfaces (Zelenka et al., 1999) and the terrain-dependent illumination conditions (Tan et al., 2010)

(Stöckli et al., 2017)

Naïve Bayesian classifier



Evaluation strategy

Validation against:

- 243 SYNOP (1991–2015), L2 → daily/monthly means
- CALIOP (2010), L2

Intercomparison (monthly means) with:

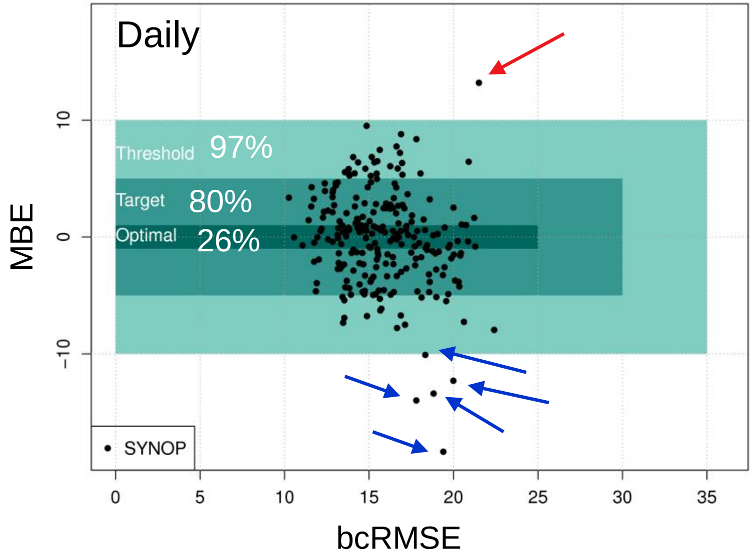
- MODIS AQUA+TERRA (2004–2015, MOD08/MYD08_M3)
- PATMOS-x (1991–2015, collocations at L2, then aggregated to monthly)
- CLARA-A2 (1991–2015, all sensors)
- CLAAS-A2 (2004–2015)
- Cloud_cci CC4CL AVHRR_PM (1991–2009)
- 1143 SYNOP aggregated to monthly at 1°×1° (2005)

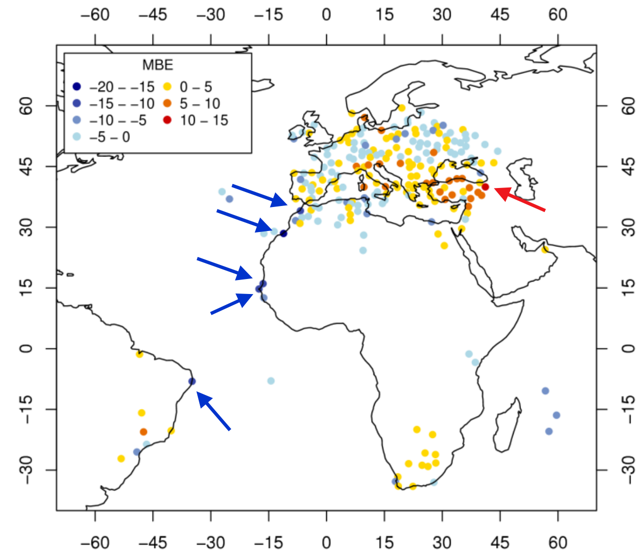
Validation against SYNOP (1991-2015)

temporal aggregation	N	mean Meteosat	mean SYNOP	MBE	bcRMSE
daily	2141165	51.74	51.90	-0.17	16.53
monthly	71040	51.77	51.91	-0.14	7.04

CFC 0-100%

It complies with the <u>optimal</u> requirements for accuracy and precision for daily and monthly means



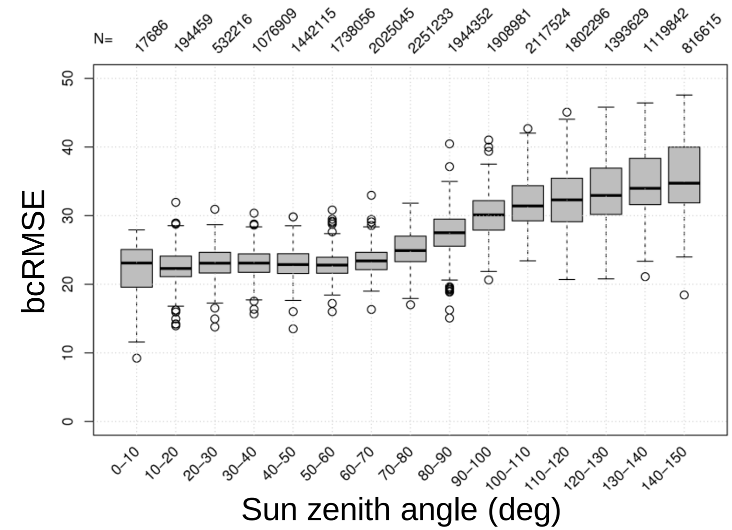


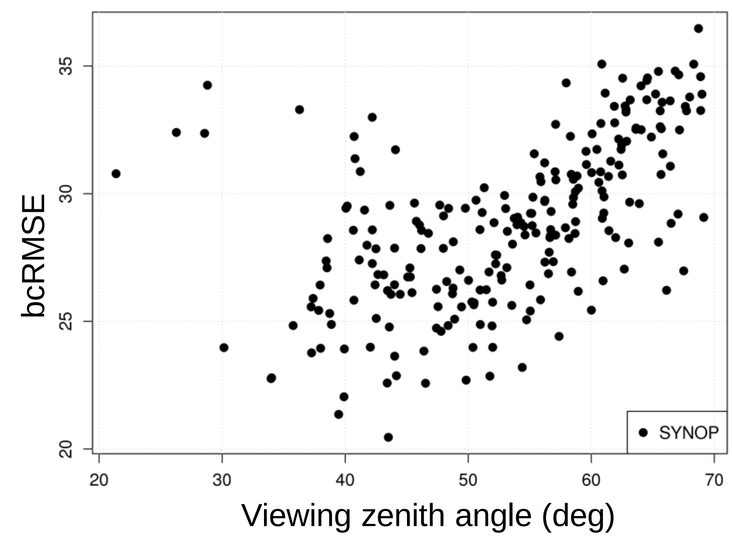
(Bojanowski et al., 2017)

Validation against SYNOP (1991-2015)

	N	MBE	bcRMSE
overall	20931127	-0.28	29.48
Cold	7973837	-0.08	31.45
Temperate	9722288	0.04	28.41
Tropical	2690808	-1.07	26.82
Arid	356551	-5.16	30.55
Ocean	187643	-4.61	29.98
day	10282717	-2.74	24.43
night	7800066	3.14	34.47
twilight	2848344	-0.76	30.39
DJF	5138479	-2.71	32.97
JJA	5393815	0.87	26.52
MAM	5253601	0.67	28.24
SON	5145232	-0.02	29.82
MFG	10456118	-0.12	30.13
MSG	10475009	-0.44	28.81
VZA < 30	233020	-6.62	31.75
VZA 30–50	5461724	-0.85	27.20
VZA > 50	15236383	0.02	30.20

Note: these stats are based on L2 matchups, so precision requirements (bcRMSE) defined for L3 do not apply





(Bojanowski et al., 2017)

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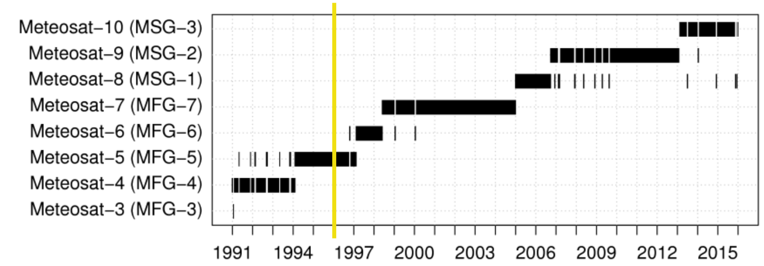
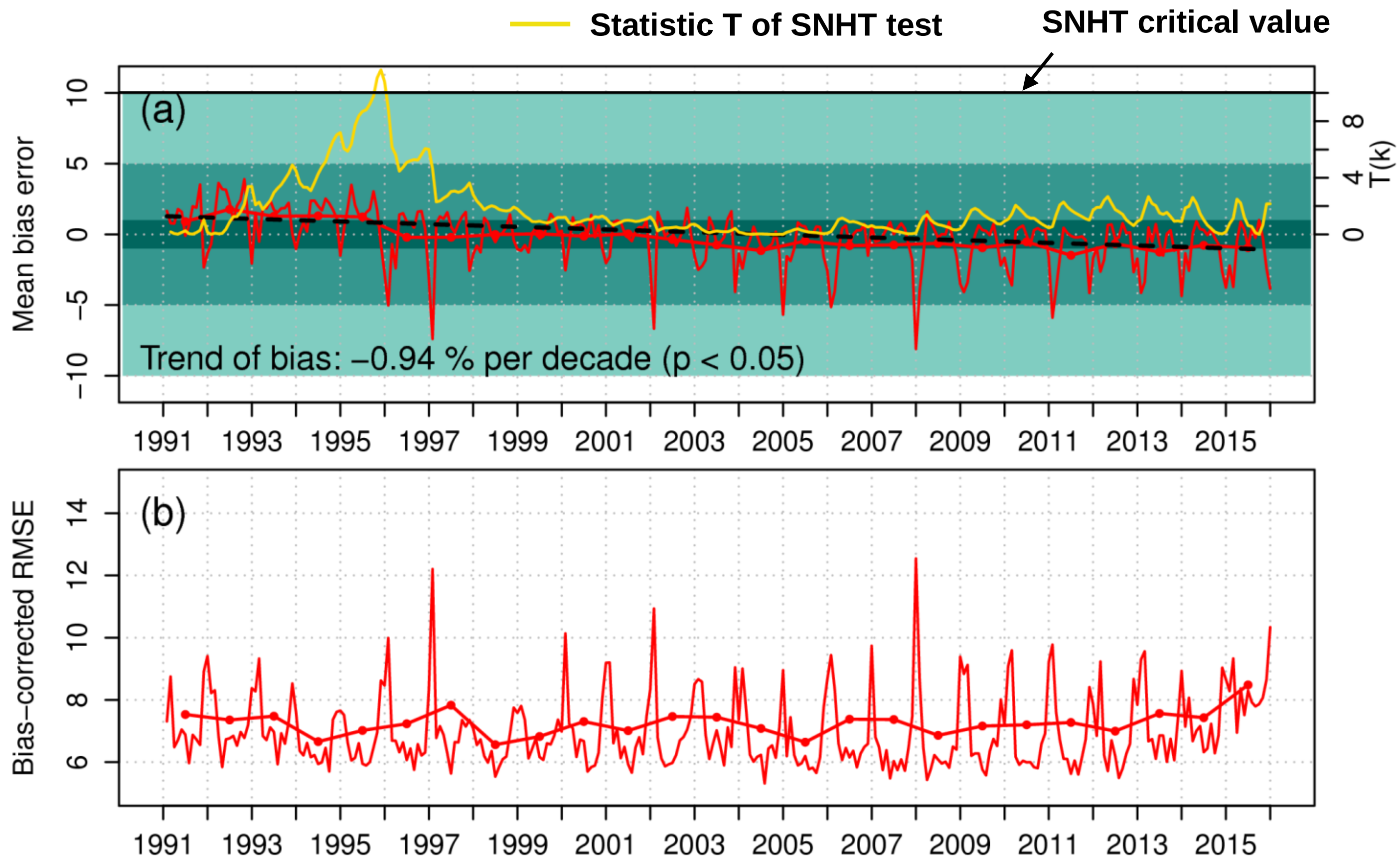
Decadal stability



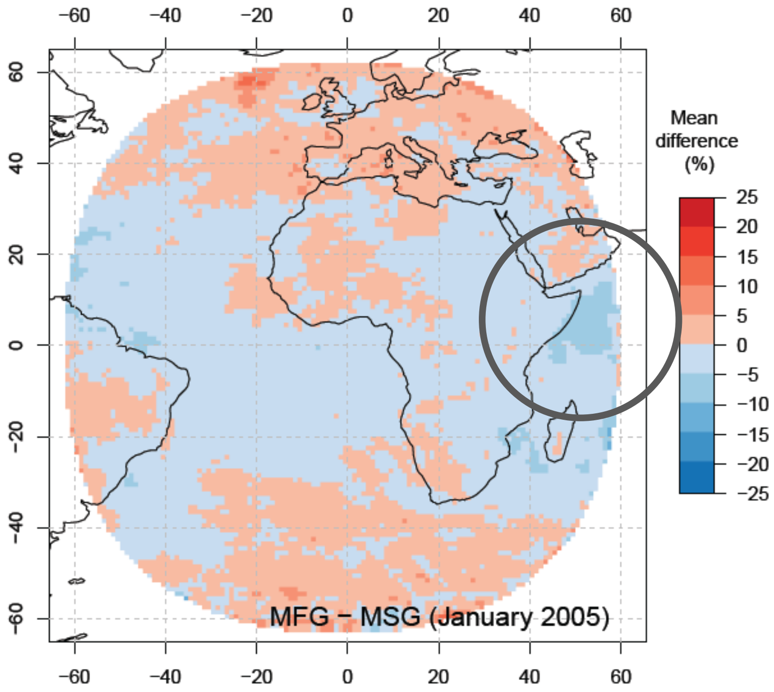


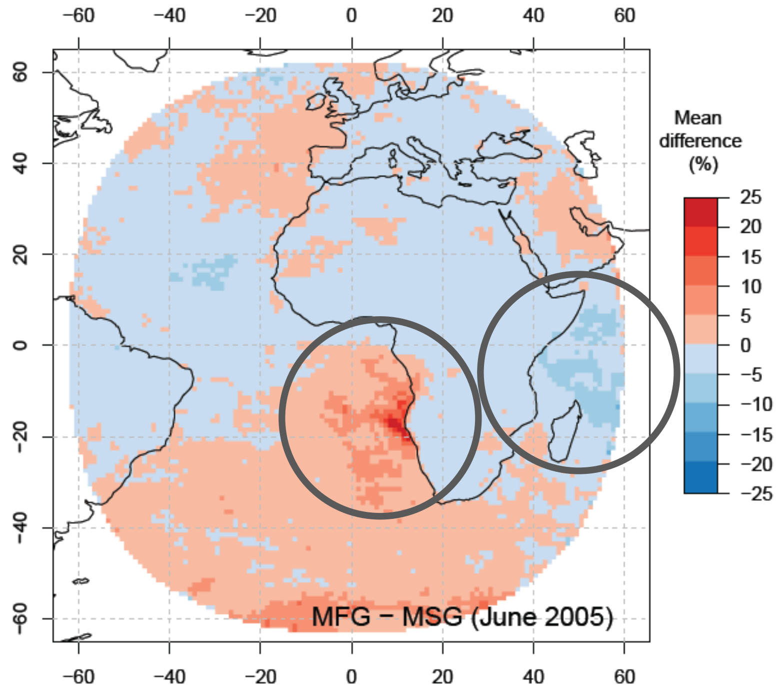
It complies with the <u>optimal</u> requirement of 1%

(Bojanowski et al., 2017)

MFG vs MSG

	N	MBE	bcRMSE
MFG – MSG (all months)	153384	-0.43	2.26
MFG – MSG (January)	12782	-0.50	2.33
MFG – MSG (June)	12782	0.04	2.63

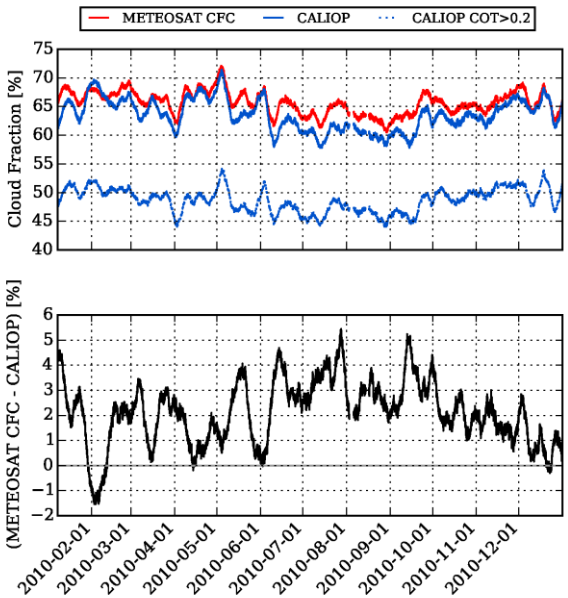




(Bojanowski et al., 2017)

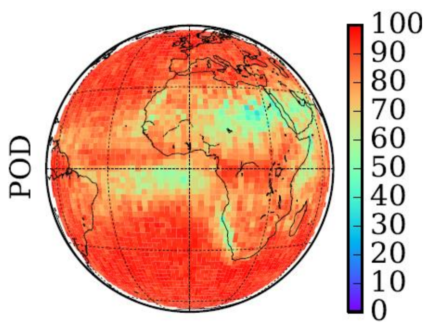
Validation against CALIOP (2010)

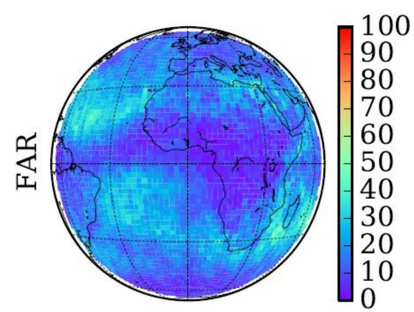
Stephan Finkensieper

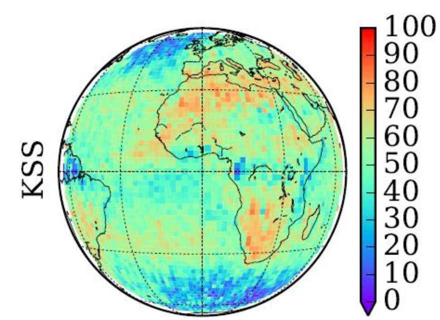


	CALIOP COT>0.0				
	All	Day	Night	Sea	Land
POD clr	70.96	70.54	71.43	70.71	71.46
FAR clr	24.05	20.85	27.25	23.62	24.69
POD cld	86.97	88.12	85.93	87.68	85.54
FAR cld	16.22	17.62	14.88	15.84	17.08
Hit rate	81.09	81.26	80.93	81.56	80.16
KSS	57.93	58.65	57.36	58.93	57.00
MBE	2.41	4.24	-0.042	2.67	1.95
bcRMSE	43.41	43.08	44.62	42.85	44.49

It complies with the target requirement of 5%

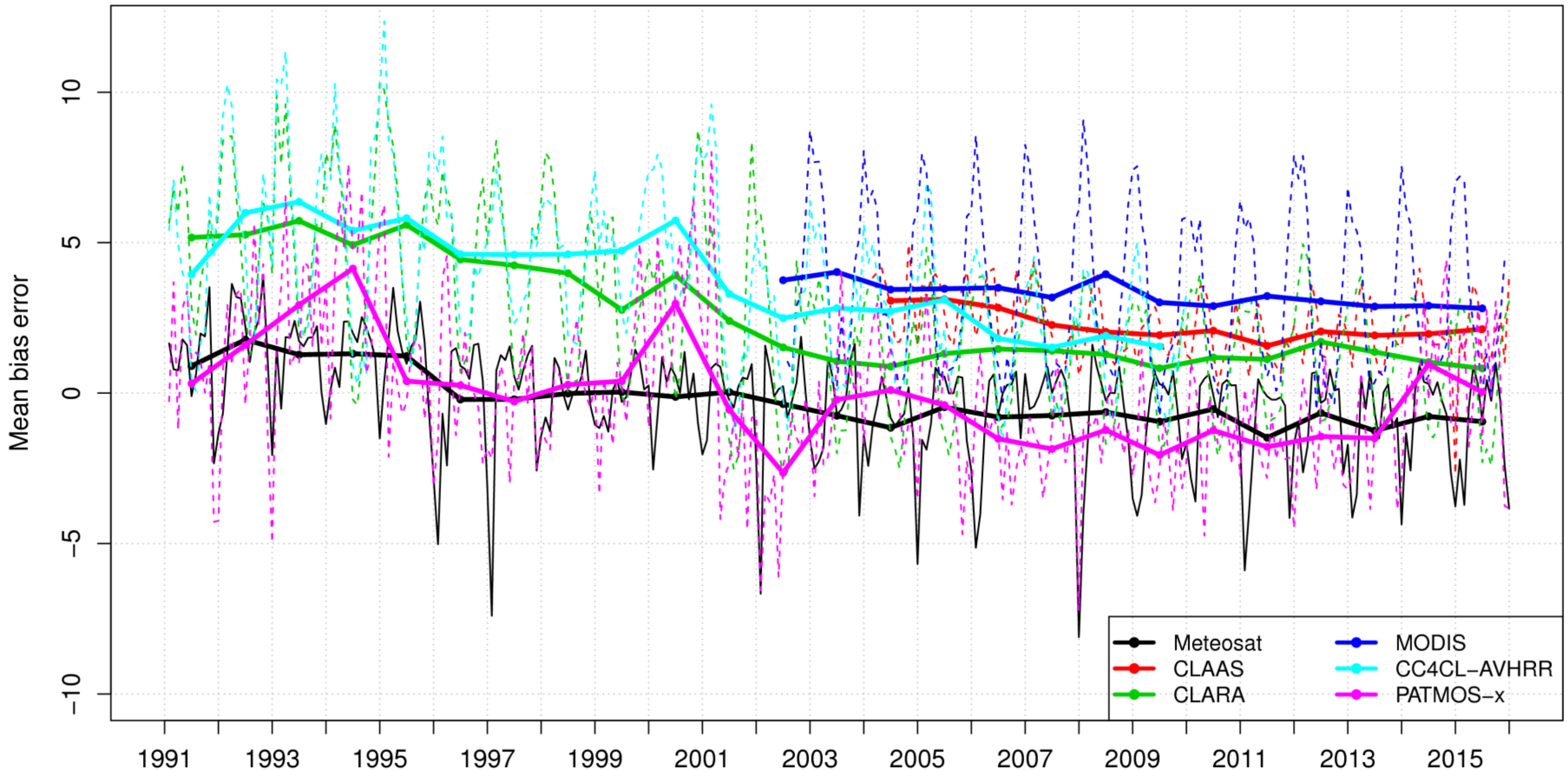






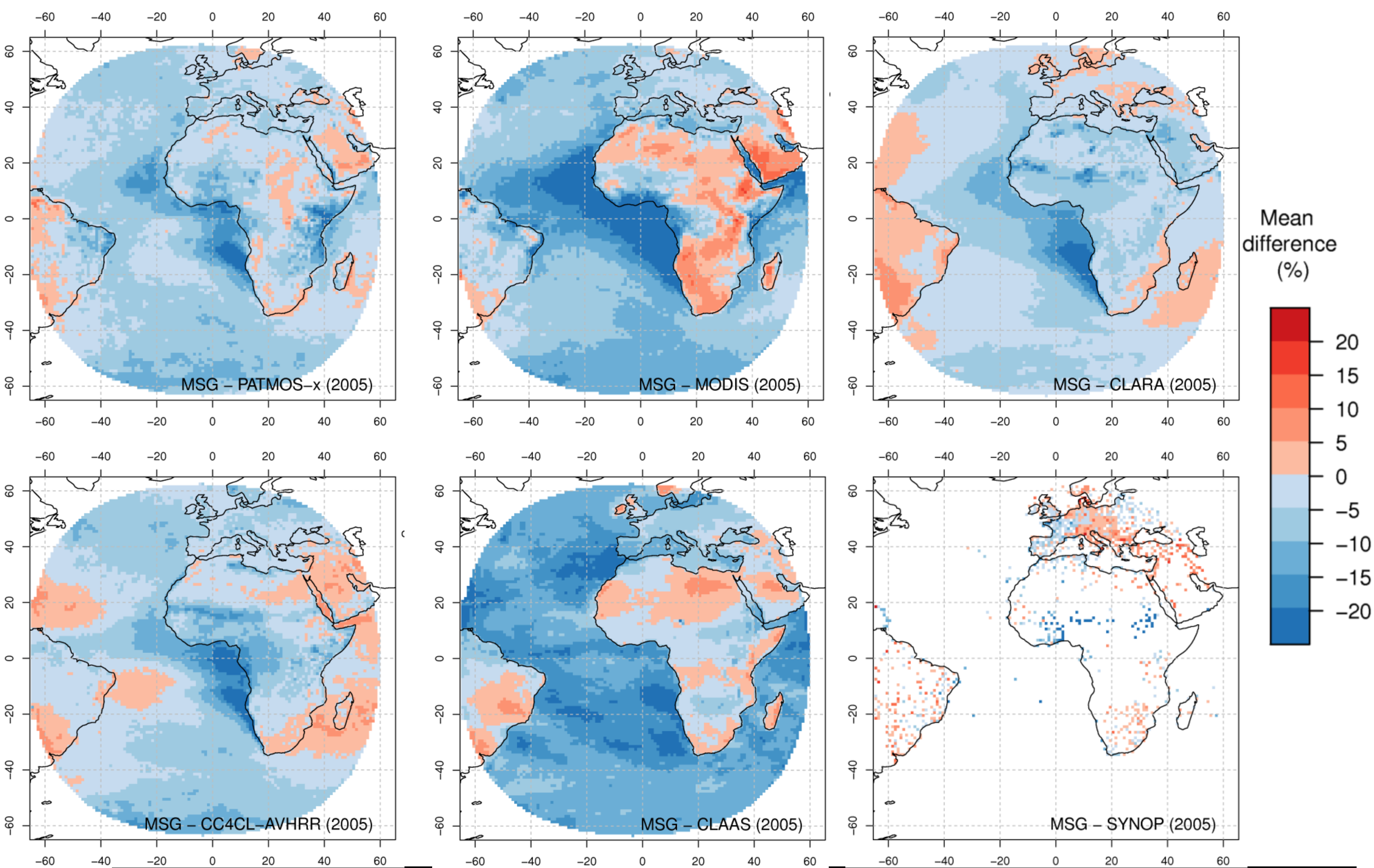
(Bojanowski et al., 2017)

Intercomparison (monthly means)



(Bojanowski et al., 2017)

Intercomparison



(Bojanowski et al., 2017)

Conclusions

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- **Meteosat-based cloud amount climate data record has been produced (1991-2015)**
- MBE and RMSE fulfil optimal requirements as compared to SYNOP
- It reveals the highest temporal stability among existing cloud CDR's
- It will be extended back to 1983 upon availability of the Meteosat 2 and 3 calibration
- It will be available (with full documentation) as daily and monthly means at www.cmsaf.eu

References

- **Bojanowski, J.S.,** Stöckli, R., Duguay-Tetzlaff, A., Finkensieper, S., Hollmann, R., 2017, Meteosat Cloud Fractional Cover Edition 1, Validation Report. Satellite Application Facility for Climate Monitoring, EUMETSAT, Germany.
- Stöckli, R., Duguay-Tetzlaff, A., **Bojanowski, J.S**, 2017. Meteosat Cloud Fractional Cover Edition 1, Algorithm Theoretical Basis Document (ATBD). Satellite Application Facility for Climate Monitoring, EUMETSAT, Germany.

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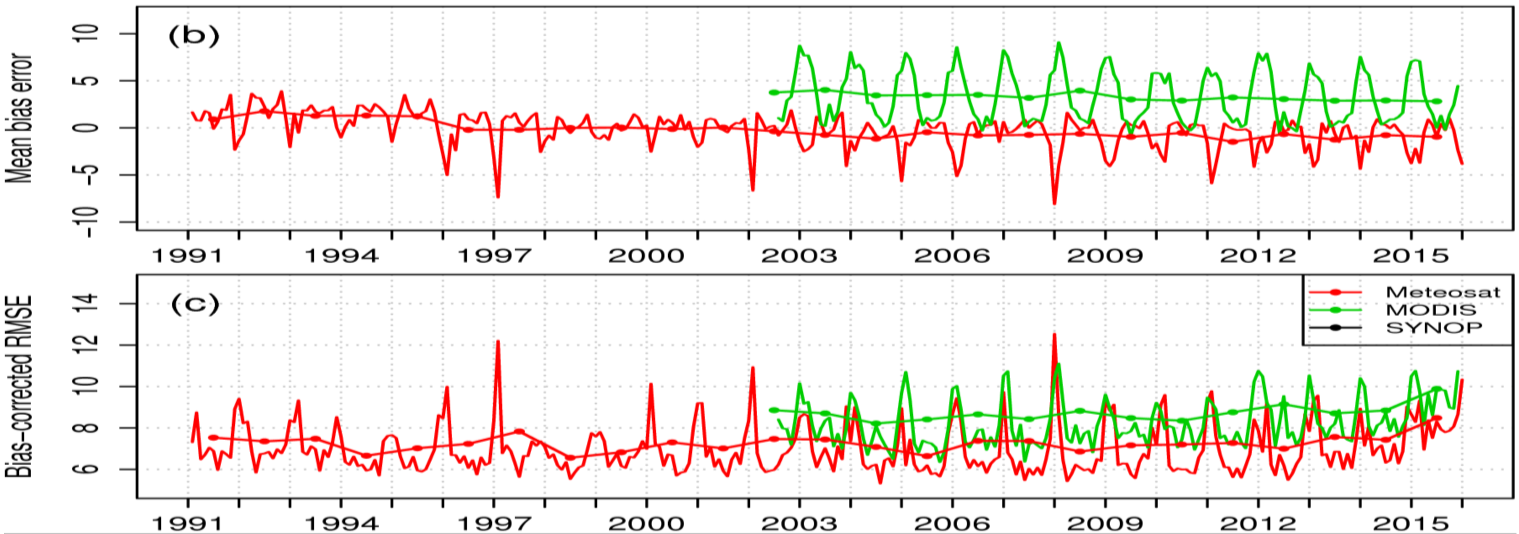
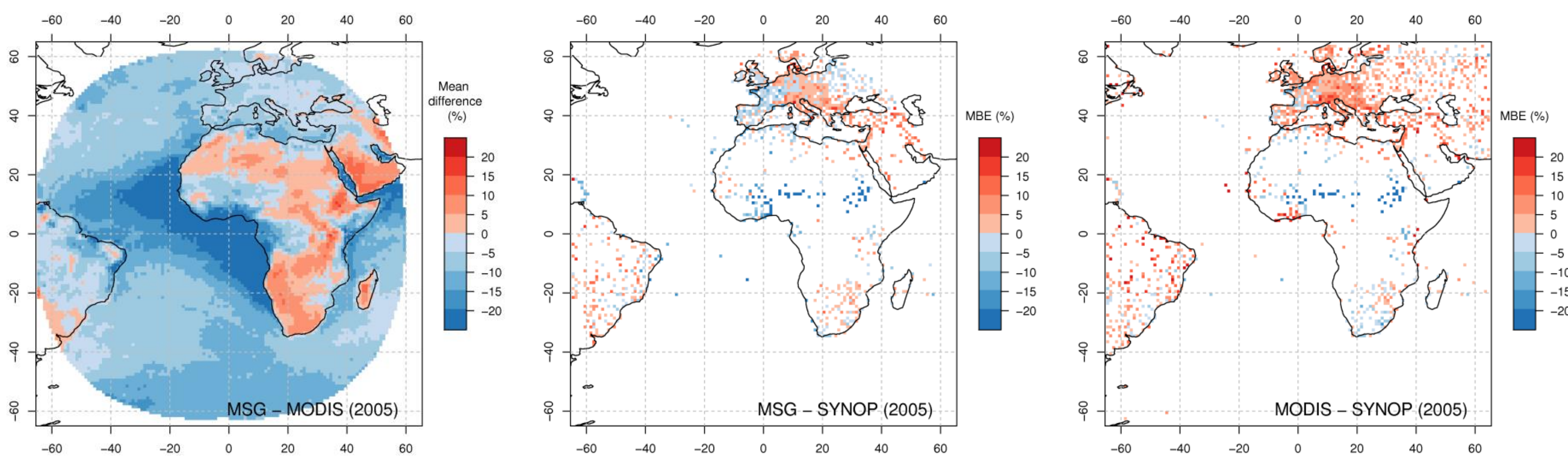
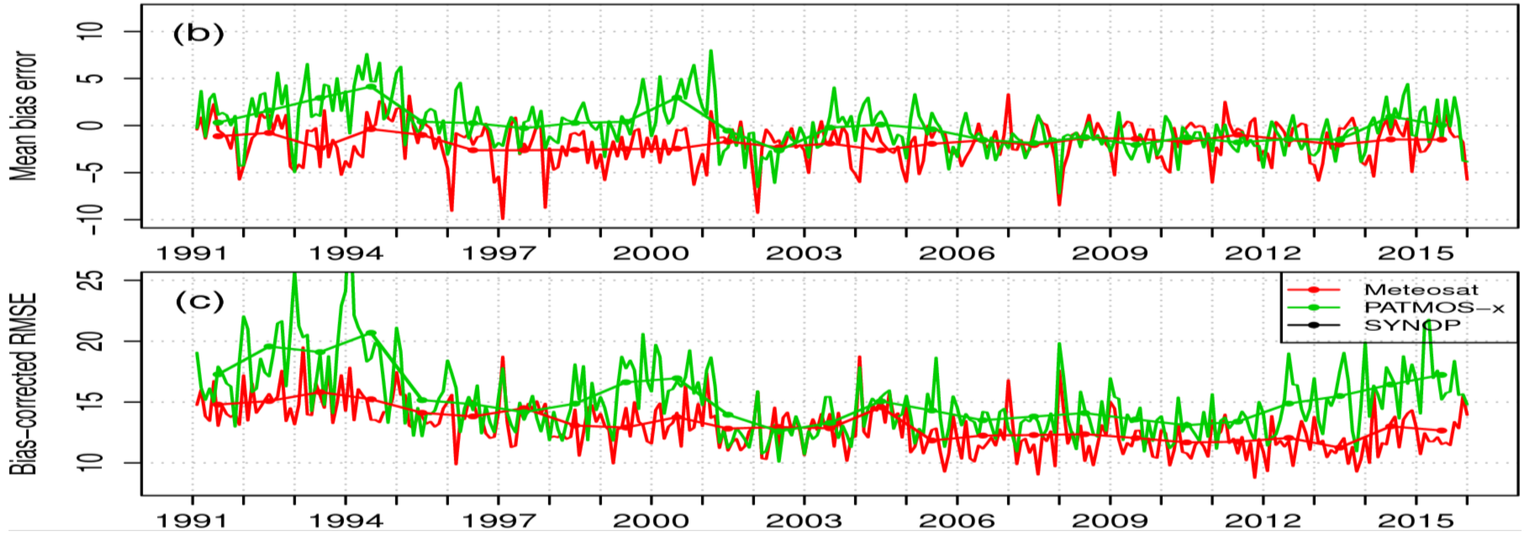
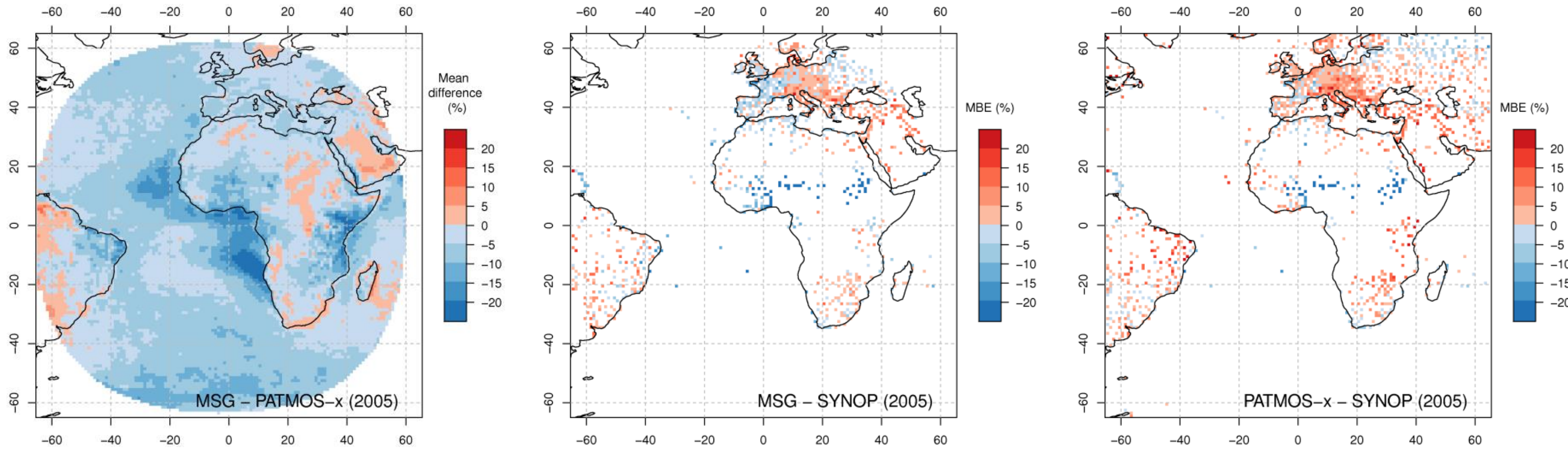
Comparison with MODIS



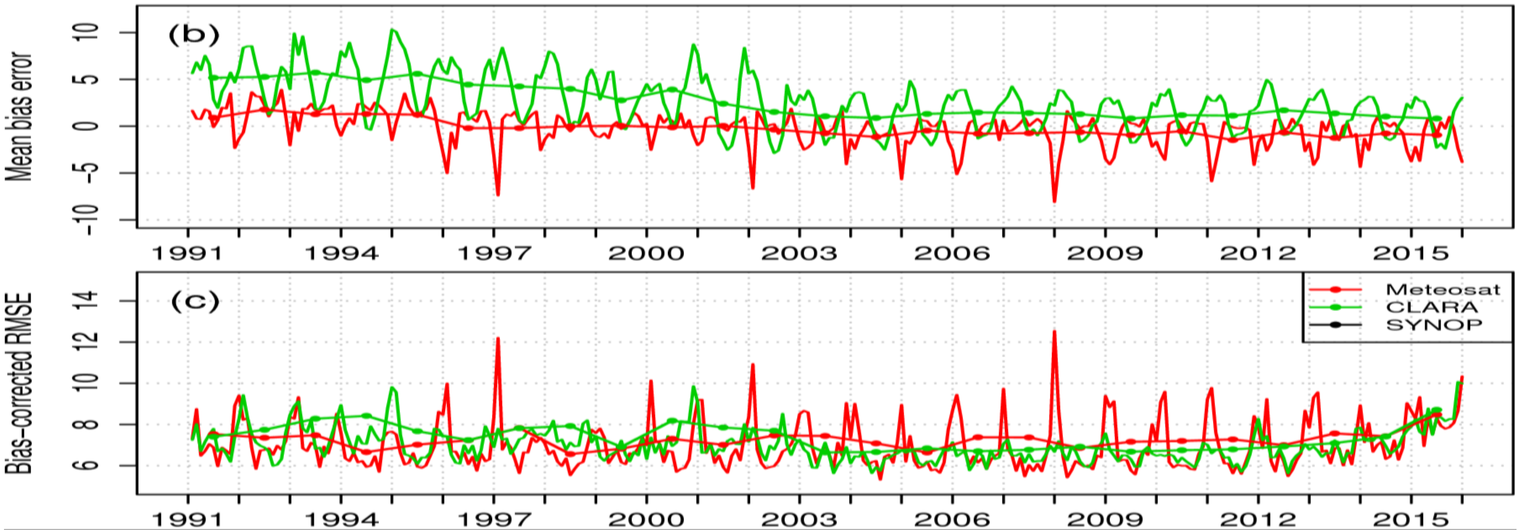


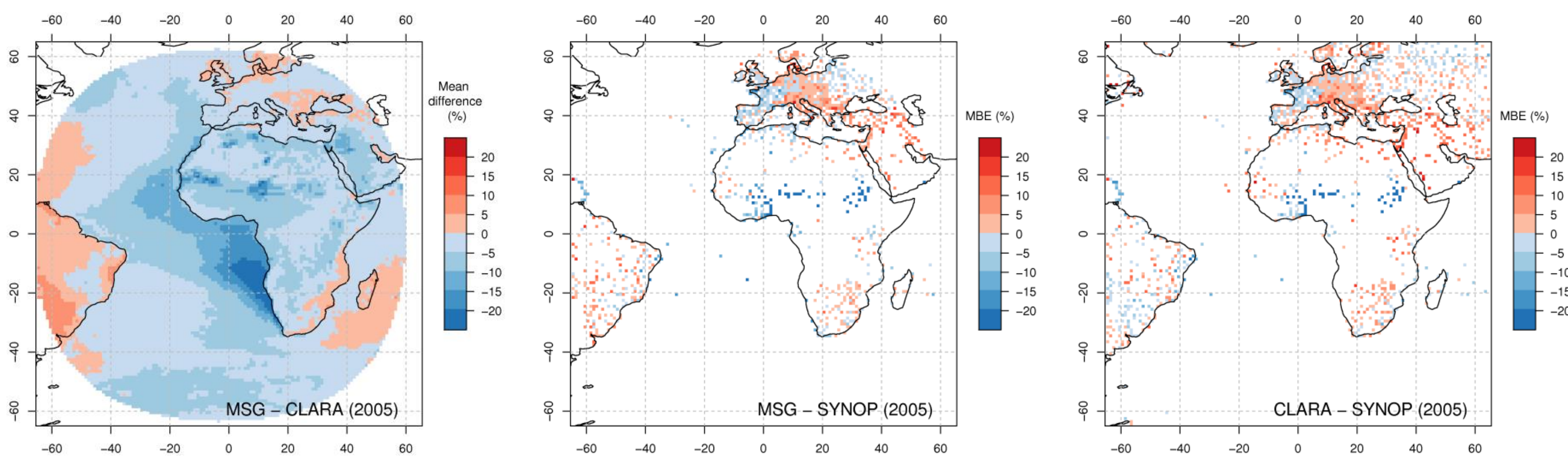
Comparison with PATMOS-x (L2→L3)



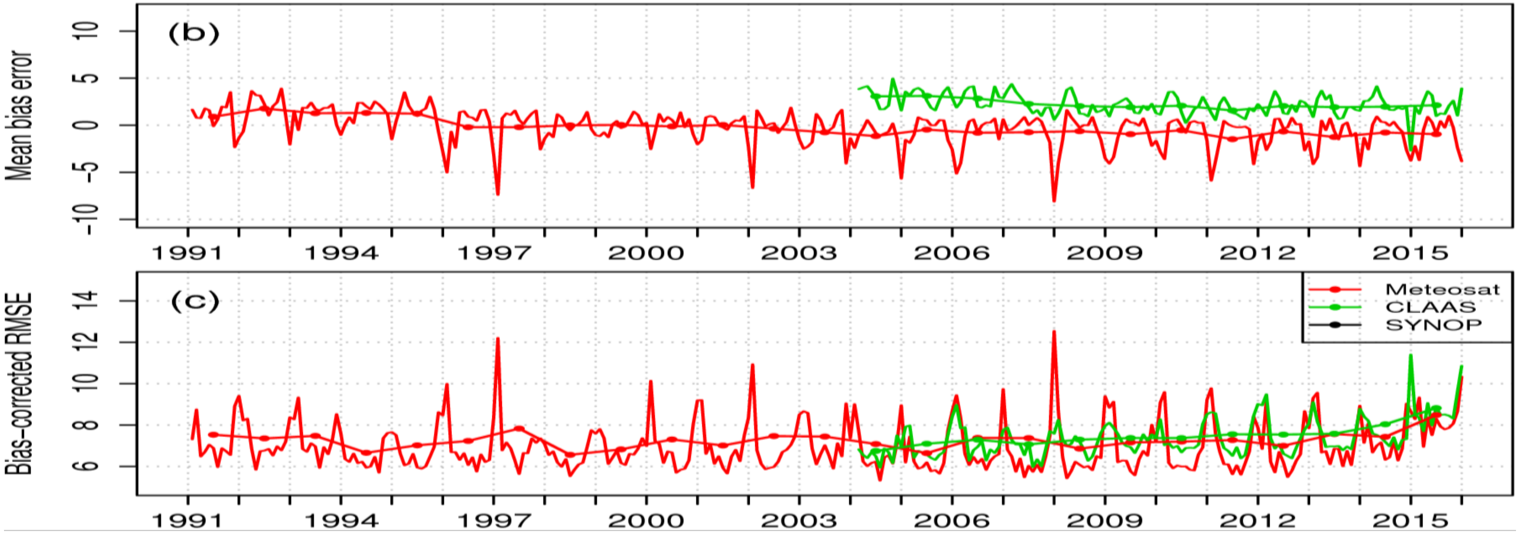


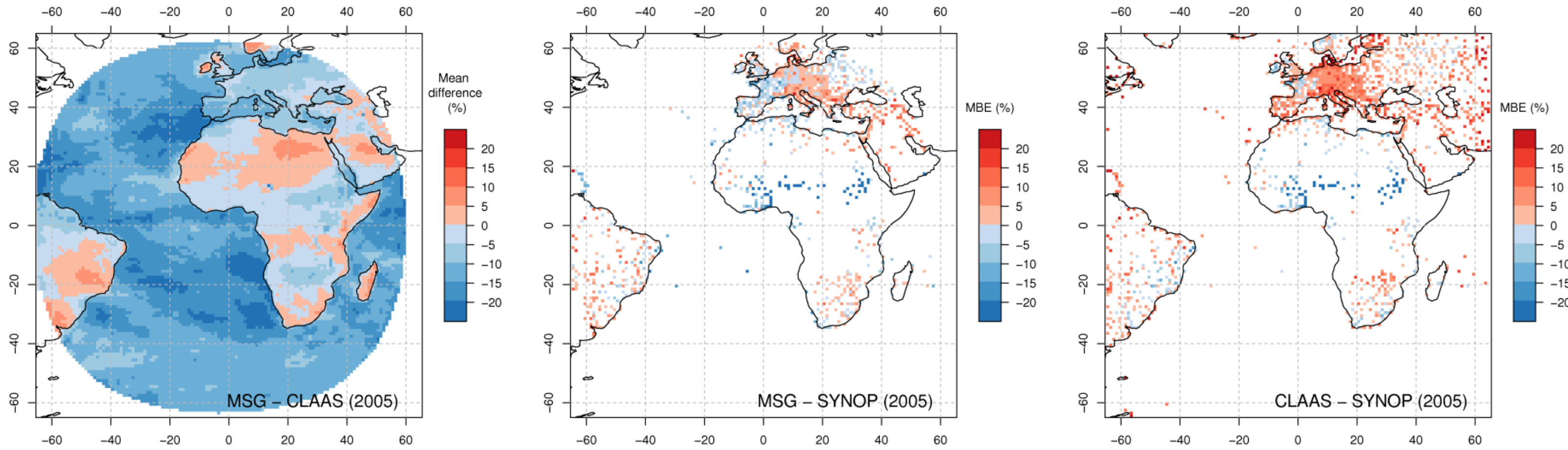
Comparison with CLARA-A2





Comparison with CLAAS-A2





Comparison with CC4CL-AVHRR